Selective Stimulation of the Hypoglossal Nerve with a Multi-Contact Cuff Electrode

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***Abstract*- The feasibility of selectively stimulating the hypoglossal nerve (XII) with a multi-contact flat-interface-nerve-electrode (FINE) was investigated for the potential application of treating obstructive sleep apnea (OSA). The main trunk of the XII was stimulated with monophasic cathodic pulses, while the elicited electroneurographic (ENG) and electromyographic (EMG) signals were recorded. Selective fascicular stimulation of the XII was achieved but with certain limitations: branches 1 and 2 could not be independently activated and the ranges of stimulus current associated with selective stimulation were small. Nevertheless, in terms of independently activating the protrudor and retractor muscle groups that are relevant to OSA, the ENG data suggests that sufficient control of pharyngeal airway patency can be achieved with this method. The functional selectivity of the FINE, however, was more difficult to address in these experiments. Selective activation of individual muscle groups was not possible but that of the retractor muscle group itself was observed. The results of this paper raise the issue of how fascicles are recruited when whole nerves are stimulated with multi-contact cuff electrodes. In order to answer this question, modification of the FINE may be warranted.**

***Keywords* – electroneurogram, electromyogram, selective stimulation, obstructive sleep apnea, hypoglossal nerve**

I. INTRODUCTION

Obstructive Sleep Apnea (OSA) is characterized by recurrent occlusions of the upper respiratory pathway during sleep. This symptom is usually attributed to both a structurally diminutive upper airway and loss of muscle tone in the musculature responsible for normal airway patency. Continuous positive airway pressure (CPAP), oral appliances and various surgical procedures (e.g., uvulopalatopharyngoplasty) are just a few examples of the current treatment options available for OSA. [3] The effectiveness of these methods is limited, however, by the low percentages of successful cases and inconsistent results.

Electrical Stimulation of the hypoglossal nerve (XII) presents a unique and promising alternative in correcting the retroglossal collapse and obstruction associated with OSA. The XII innervates both the extrinsic and intrinsic muscles of the tongue as well as the geniohyoid (GH) muscle, which connects the mandible to the hyoid bone. The extrinsic muscles can be further categorized as protrudor (genioglossus (GG)) and retractor (hyoglossus (HG) and styloglossus (SG)) muscles.

An earlier study involving electrical stimulation of the XII, particularly the GG muscle, yielded a significant increase in inspiratory airflow and a reduced number of apneic episodes, which suggested that stimulation of the protrudor muscle was responsible for removing the obstruction. [6] Their assessment of the results, however, fell short of addressing the mechanisms involved with the collapsibility of the pharyngeal airway. As later studies demonstrated, independent stimulation of the GG may not suffice in removing an obstruction if nasopharyngeal pressures are significantly low. [1,2] It is the co-activation of both the protrudor and retractor muscles that not only increases the inspiratory flow rate but also the airway patency (i.e., decreases pharyngeal collapsibility). This suggests that improved control of pharyngeal airway patency can be achieved if both protrudor and retractor muscles can be independently recruited.

To this end, the stimulation selectivity of a single nerve cuff implanted on the XII was investigated in this paper. Using a flat-interface-nerve-electrode (FINE) [7], multi channel ENG and EMG data sets were acquired for each stimulating contact. The fascicular (ENG) and functional (EMG) selectivities of the FINE were subsequently evaluated.

II. METHODOLOGY

The hypoglossal nerve (XII) of 2 adult beagles, which were anesthetized with fluothane (i.e., halothane), was exposed by blunt dissection. A 17-contact FINE cuff electrode, which reshaped the nerve over a period of approximately 8 hours, was implanted immediately proximal to the branching point of XII. The platinum contacts were arranged in a tri-polar configuration: 13 contacts (each 0.5x0.5 mm, inter-contact distance 1 mm) were placed in the middle of the cuff with 7 on top and 6 on the bottom, while each pair (i.e., top and bottom) of the remaining 4 contacts (each 0.5x6 mm) were positioned both proximal and distal to the middle contacts. The width, height and length of the cuff window were 7.62 mm, 0.3 mm and 10 mm, respectively.

Three FINE cuff electrodes were also implanted onto each of the branches (i.e., 1 medial and 2 lateral) of the XII. These were labeled according to the neuro-anatomical description given in the literature [5]: the first lateral (branch 1), medial (branch 2) and second lateral (branch 3) branches innervated the GH, GG, and HG/SG muscle groups, respectively. The dimensions of the cuff windows were as follows: branch 1 (3x0.2x10 mm), branch 2 (4x0.5x10 mm) and branch 3 (3x0.2x10 mm). Multi-strand stainless steel wires were also implanted into the identified muscle groups for EMG recordings.

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Single cathodic current pulses (PW = 50 μs, I = 0 to 1.5 mA) were applied to each of the 13 contacts of the main FINE while the evoked ENG and EMG signals were recorded into a PC using a National Instrument data acquisition board (PXI-6071E) for 10 ms durations following stimulation. Each data acquisition was repeated 64 times, sampled at 40 kHz and band-pass filtered (10 Hz to 10 kHz). It is noted that the 4 outer contacts of the main FINE were used as the anodic return, i.e., tripolar stimulation, in order to minimize the recorded stimulus artifacts. The average (n = 64) peak-to-peak voltage (Vpp) was calculated for each stimulus level and normalized using the maximum calculated value of Vpp.

III. RESULTS

Fascicular selectivity: The recruitment curves obtained from the recorded ENG data showed that the majority of the contacts (18/26) of the FINE failed to yield any significant fascicular selectivity (i.e., stimulate one fascicle without eliciting activity in other fascicles). For the contacts that did exhibit such properties, the extent of selectivity was limited to within a given range of stimulus. Examples of selective contacts are presented in figure 1(a) and 1(b), respectively. The recruitment curves and corresponding ENG signals (evoked at I = 0.2 mA for both contacts) are given. Although independent stimulation of branch 1 or branch 2 was not possible with this particular stimulation paradigm, it is interesting to note here that contact 5 elicited neural activity in the 2 fascicles associated with pharyngeal airway opening. It is clear from figure 1(a) that the ENG for branch 3, which innervates the HG and SG, is absent. Figure 1(b), on the other hand, clearly demonstrates selective stimulation of branch 3, which innervates the retractor muscle groups. As previously mentioned, the current range of selective stimulation is limited (0.12 to 0.2 mA).

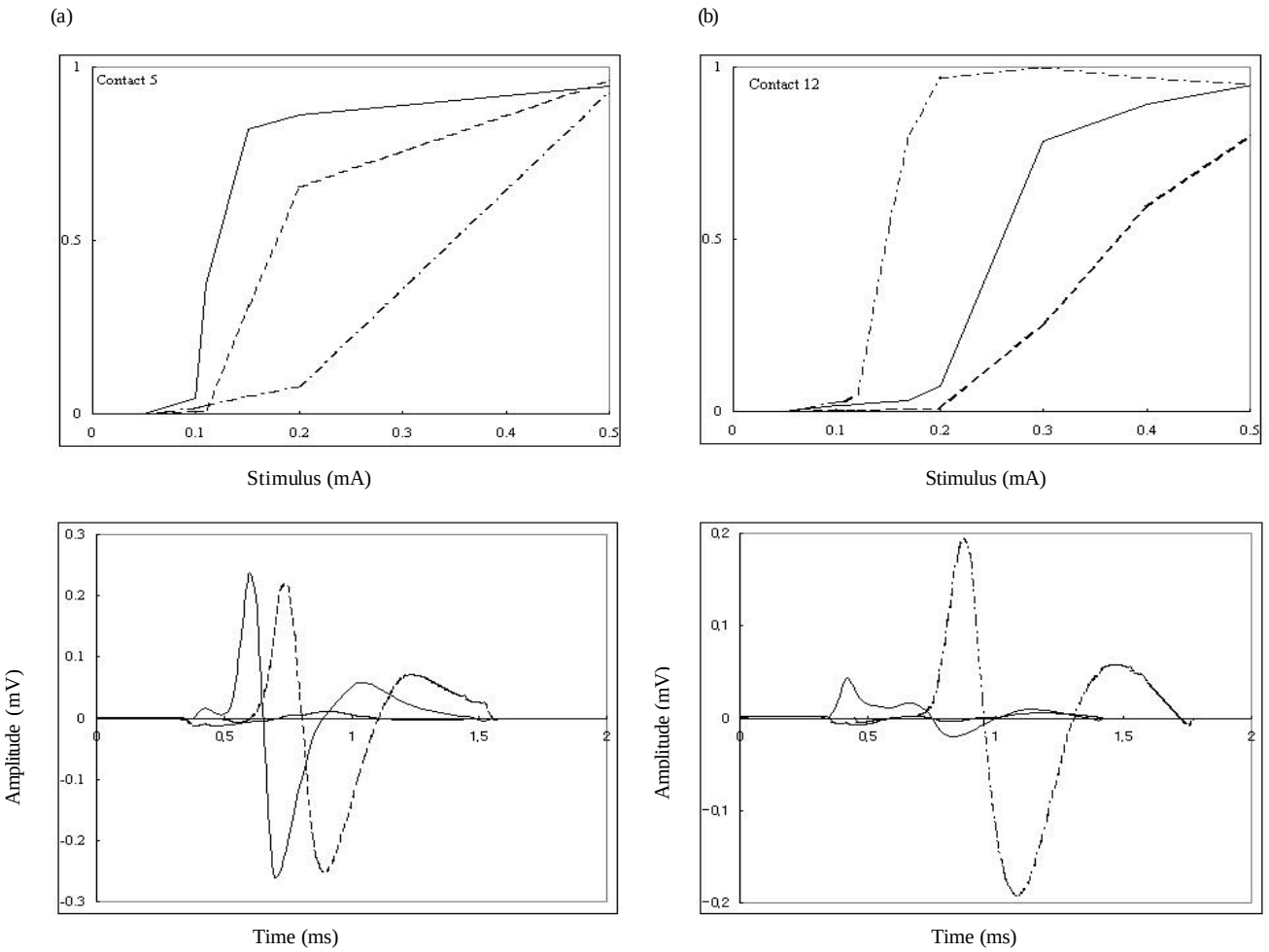

Figure 1. Example of selective contacts of the FINE. The recruitment curves used normalized ENG data, while the ENG signals were recorded compound action potentials. Note: branch 1(solid line), branch 2(dash) and branch 3 (dash dot): the line types of both graphs are consistent.

Functional Selectivity: An alternative method of analyzing the experimental data is achieved by comparing the recruitment curves of the evoked EMG signals from each muscle group. Similar to what was found in the previous section, individual activation of either of the 4 muscle groups was not achieved. A typical non-selective recruitment curve is shown figure 2(a), while 2(b) shows a contact that is selective for the HG and SG muscles, i.e., retractors.

In both of these plots, muscle groups associated with fascicles located distally from the stimulating contact are being recruited. For example, in figure 2(a), the GH and the HG are the dominant muscle groups that are recruited.

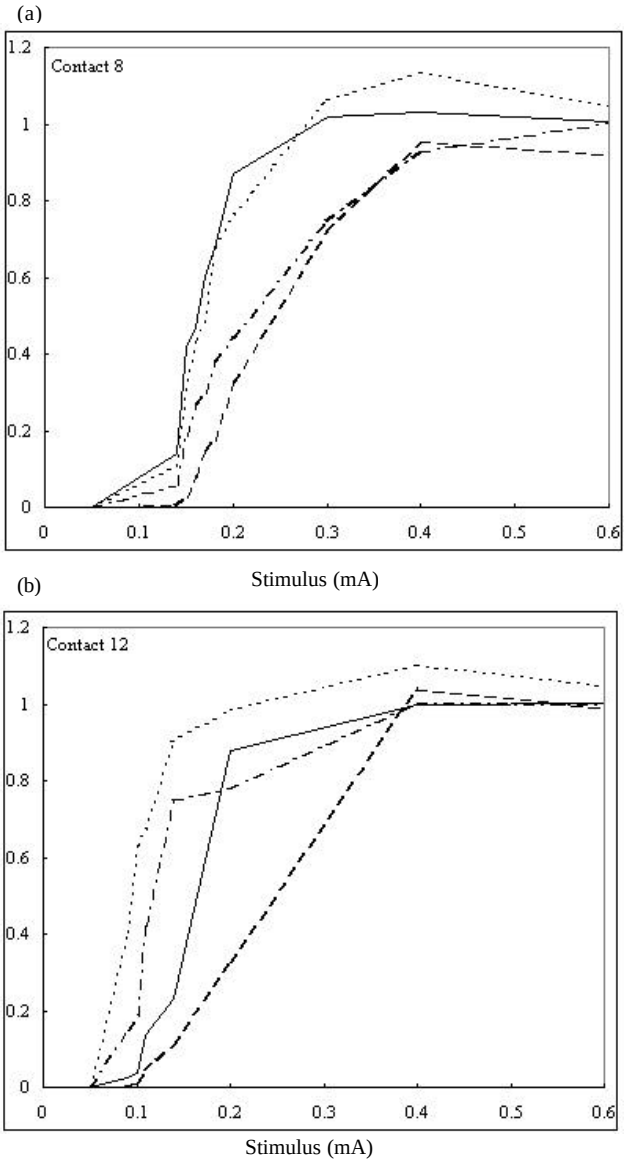

Figure 2. Normalized recruitment curves for functional selectivity. Note: GH (solid), GG (dash), HG (dot) and SG (dash dot): the line types of both graphs are consistent.

The fascicle that innervates HG (i.e., branch 3), however, is located on the opposite side of the cuff with respect to contact 8. This is also observed in figure 2(b): the fascicle innervating GH (branch 1) is located opposite to contact 12.

IV. CONCLUSION

The most critical point of this study is why fascicles (i.e., muscle groups), located distally from the stimulating contact, are being recruited. One possible explanation may be that fascicular recruitment is dependent upon the diameter of the fascicle. [8] If such were the case, then it would be difficult to selectively activate the GG, since this is the largest fascicle located within the XII. According to Sahin et al. [4], however, the GG can indeed be selectively recruited when stimulating with a cuff electrode. To further complicate this issue, there are certain aspects of these experiments that also need to be addressed: the exact position of the stimulating electrode contacts with respect the hypoglossal nerve, the method of stimulation (tripolar vs. monopolar) and the precise origin of the recorded EMG signals. It is clear that future experiments will have to minimize these variables, while the number of contacts may have to be increased or the size of the exposed platinum decreased in order to achieve selective stimulation.

Nevertheless, the results of this study clearly showed that selective activation of both the protrudor and retractor fascicles can be achieved. And this may be sufficient for effectively treating the symptoms associated with OSA.

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